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DIELECTRIC PROPERTIES OF CALCIFIED TISSUE - THE BONE

Abdul Gafoor Shaik[1] and Mohammed Abdul Aleem Siddiqui[2]

[1]Department of Physics, Muffakham Jah College of Engineering and Technology, Hyderabad – 500 034, India

[2]Physics Section, Department of Science, Humanities and Management, Deccan College of Engineering and Technology, Hyderabad – 500001, India

Abstract: The paper reports data on dielectric parameters such as dielectric constant and dielectric loss of scapula, rib and femur bones of the animals - Ox and Camel. For the dielectric measurements, a two terminal cell, constructed in Biophysics Laboratory, Nizam College, Hyderabad, was used. A significant variation in dielectric parameters is observed with respect to type of bone as well as animal.

Key words: Dielectric constant, Dielectric Loss Femur, Rib, Scapula, Ox, Camel, jig.

1. Introduction

The dielectric properties of matter are primarily of interest to the physicists and electrical engineers. These have also proved to be of importance and use in the understanding and development of other field knowledge, such as chemical and biological sciences. The study of dielectric properties of macromolecules, cells and tissues of biological interest become part of the inter-disciplinary armory of the biological sciences. Advances in such studies certainly will benefit to some branches of medicine.

In everyday life, bones are under constant remodeling depending on the degree and type of functional stress. Based on electrical nature of mechanical stimulation of bone, dielectric and electrical properties are closely linked. Obviously, more detailed information on the basic electrical and dielectric properties of bones could result in the development of tools for diagnostic and therapeutic applications [1]. A detailed knowledge of electrical and dielectric properties is also necessary to determine electrical field and current distribution during electrical stimulation of bone fracture [2].

The physiological effects of electric currents had drawn the attention of the researchers in the 19th century. "Electrotherapy" came to be widely practiced by physicians. The early theories of Cole [3] and Danzer [4] for the dielectric properties of cell suspensions were further simplified and extended by Schwan and co-workers [5].

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Studies of dielectric properties of biological materials remain an active area of research. With the introduction of modern network analyzer and time domain measurement systems, the determination of dielectric properties of the biological samples is easier and this should encourage increased efforts in this field. Many opportunities exist and fundamental problems remain to be solved.

Today, work on dielectric properties of biological systems and their response to electric fields is being conducted at an increasing number of places. This work will surely provide new insights into how electrical fields can act on cells and tissues and will lead to beneficial applications of electric fields and currents. However, to get a deeper insight into the dielectric nature of the material, parameters like dielectric constant (ε'), dielectric loss (ε''), dissipation factor ($\tan\delta$), are needed.

Bovine trabecular bone is known to be denser and less porous than the human trabecular bone [6 -8].

In the present study a comparison has been made between dielectric properties of femur, rib and scapula bone of ox and camel. This paper constitutes a step towards the application of dielectric measurements for in bone diagnostics in vivo.

2. Materials and Method

Fresh bones such as femur, rib and scapula of ox and camel were collected from slaughterhouse for present investigations. Fleshly material present on the bone is removed. Specimens (pellets or discs) were cut from mid region of the bone (Fig. 1).

Fig. 1: Specimens (pellets or discs) were cut from mid region of the bone

For the dielectric measurements, a two terminal cell was constructed in Biophysics Laboratory, Nizam College, Hyderabad. The cell consists of two parallel circular plates made up of copper. The diameter and thickness of the plates are 2 cm and 0.2 cm respectively. The lower circular plate electrode plugs directly into the live terminal of the capacitance measuring bridge while the upper one, at earth potential is moved by means of a micrometer having least count 0.001 cm. This serves two purposes. One is to apply a slight pressure on the specimen placed between them and the other is to measure the separation of the plates or the thickness of the sample. To eliminate capacitance due to leads, the capacitance (C_a) of the cell for different inter-electrode spacing (d) was measured. A plot is drawn between air capacitance on y-axis and 1/d on x-axis. The plot is linear and the capacitance (C_a) at infinite distance of the plates (i.e. 1/d = 0) gives the value of lead capacitance (C_L) of the cell. This value is to be subtracted from the measured value of capacitance with the sample ($C_s^{'}$) and with air ($C_a^{'}$) to have an exact value of the capacitance with sample (Cs) and with air (Ca).

$$i.e\; C_s = C_s^{'} - C_L \; and \;\; C_a = C_a^{'} - C_L$$

Fig. 2: Jig

A commercial digital LCR meter (Systronics, SDLCR 925) was used to measure the capacitance and dissipation factor (tanδ). To have a comparative study of dielectric behaviour of femur, rib and scapula in the applied alternating filed of frequency 1 kHz capacitance and dissipation factor were measured with and without the sample in the cell. All the measurements were taken at room temperature. The dielectric constant of the sample is given by $\varepsilon' = \frac{C_s}{C_a} = \frac{C_s^{'} - C_L}{C_a^{'} - C_L}$

where C_s = actual capacitance of the cell with the sample; C_a = actual capacitance of the cell with air; C's = measured capacitance of the cell with sample; C'a = measured capacitance of the cell with air; C_L = lead capacitance.

The dielectric properties were investigated by applying electrical current to samples through dielectric cell using commercial LCR meter (Systronics, SDLCR 925).

Knowing the value of ε' and tanδ, the dielectric loss was calculated by using the formula,$\varepsilon'' = tan\delta$ Xε'

The dielectric constant and dielectric loss of bone specimen were measured along its z-direction. But it was not possible to measure along x and y - directions due to the limitations in the dimensions of the specimens.

3. Results and Discussion

Table 1- 6 present the data on the dielectric parameters such as dielectric constant (ε'), dielectric loss (ε''), of femur, rib and scapula of ox and camel taking 5 to 10 samples of each in normal condition. The parameters were determined at 1 kHz frequency at room temperature. Here, the standard deviation values of the parameters reveal the variation among the different bone specimens, but not the uncertainty of the measurement. It is evident from the data that there exists a considerable variation in the observed parameters (Table 1 – 6). The absolute values of electric and dielectric parameters determined in this study were in agreement with earlier studies [9].

Dielectric constant and dielectric loss is more in camel bone than in ox bone irrespective of type of the bone. Similarly, Dielectric constant and dielectric loss is more in femur when compared to that of rib and scapula.

$$i.e., \quad \varepsilon_f' > \varepsilon_r' > \varepsilon_s'$$

$$i.e., \quad \varepsilon_f'' > \varepsilon_r'' > \varepsilon_s''$$

Results on dielectric parameters of femur, rib and scapula reveal considerable variation in different bone samples and also in different specimens of the same bone, obtained from the various parts of the bone (Fig.1). This may be attributed to the inhomogeneous deposition of calcium phosphate and may be due to significant variation in water content of the bones.

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Table 1: Data on dielectrical parameters of ox femur in normal condition

Sl. No	Sample code	Capacitance (pf)		Tan δ	Dielectric constant ε'	Dielectric loss ε "
		Without sample (ca')	With sample (cs')	With sample		
1	OF01	2.1	5.55	1.28	4.14	5.29
2	OF02	2.2	8.25	0.95	6.04	5.74
3	OF03	2.1	7.62	1.82	6.02	10.95
4	OF04	2.1	6.69	1.65	5.17	8.54
5	OF05	2.1	11.82	2.05	9.84	20.16
6	OF06	2.1	6.15	1.23	4.68	5.76
7	OF07	2.3	7.05	1.33	4.65	6.19
8	OF08	2.4	10.59	0.91	6.85	6.23
				Mean:	5.92	8.61
				S.D:	±1.82	±5.041

Table 2: Data on dielectrical parameters of ox rib in normal condition

Sl. No	Sample code	Capacitance (pf)		Tan δ	Dielectric constant ε'	Dielectric loss ε"
		Without sample (ca')	With sample (cs')	With sample		
1	OR01	12.8	16.8	0.64	5.00	3.20
2	OR02	12.8	18.8	0.62	7.00	4.34
3	OR03	12.9	16	0.64	3.82	2.44
4	OR04	13	18.6	0.59	5.67	3.34
5	OR05	13	19.2	0.57	6.17	3.52
6	OR06	14.6	21.6	0.49	3.50	1.72
7	OR07	12.9	17.7	0.63	5.36	3.38
8	OR08	13.1	17.3	0.62	4.23	2.62
9	OR09	12.9	18.6	0.58	6.18	3.59
10	OR10	12.9	17.7	0.65	5.36	3.49
11	OR11	12.9	22.3	0.6	9.55	5.73
12	OR12	13.9	21.1	0.57	4.43	2.52
				Mean:	5.52	3.32
				SD:	±1.64	±1.02

Table 3: Data on dielectrical parameters of ox scapula in normal condition

Sl. No	Sample code	Capacitance (pf)		Tan δ	Dielectric constant ε'	Dielectric loss ε"
		Without sample (ca')	With sample (cs')	With sample		
1	OS01	13.2	21.2	0.58	6.71	3.89
2	OS02	13.9	18.4	0.55	3.14	1.73
3	OS03	14.4	21.6	0.5	3.77	1.88
4	OS05	14.5	21.7	0.48	3.67	1.76
5	OS06	13.1	19.4	0.56	5.85	3.27
				Mean	4.63	2.51
				SD:	±1.56	±1.01

Table 4: Data on dielectrical parameters of camel femur in normal condition

Sl. No	Sample code	Capacitance (pf)		Tan δ	Dielectric constant ε'	Dielectric loss ε"
		Without sample (ca')	With sample (cs')	With sample		
1	CF02	7	12	6.02	6.00	36.12
2	CF03	7	12	6.6	6.00	39.60
3	CF04	7	13	5.5	7.00	38.50
				Mean:	6.33	38.07
				SD:	±0.58	±1.78

Table 5: Data on dielectrical parameters of camel rib in normal condition

Sl. No	Sample code	Capacitance (pf)		Tan δ	Dielectric constant ε'	Dielectric loss ε''
		Without sample (ca')	With sample (cs')	With sample		
1	CR01	13.4	24.8	0.48	8.13	3.90
2	CR02	13.5	18.7	0.53	4.06	2.15
3	CR03	13.4	22.8	0.5	6.88	3.44
4	CR04	13.6	22.5	0.49	5.94	2.91
5	CR05	13.7	23.8	0.53	6.32	3.35
6	CR06	14	22	0.49	4.64	2.27
7	CR07	13.6	26.1	0.46	7.94	3.65
8	CR08	13.3	23.8	0.51	8.00	4.08
9	CR09	13.7	24.5	0.49	6.68	3.28
10	CR10	13.8	22.2	0.48	5.20	2.50
				Mean:	6.38	3.15
				SD:	±1.43	±0.67

Table 6: Data on dielectrical parameters of camel scapula in normal condition

Sl. No	Sample code	Capacitance (pf)		Tan δ	Dielectric constant ε'	Dielectric loss ε''
		Without sample (ca')	With sample (cs')	With sample		
1	CS01	14	21.5	0.49	4.41	2.16
2	CS02	13.1	21.2	0.53	7.23	3.83
3	CS03	13.2	18.8	0.66	5.00	3.30
4	CS04	13.1	19.7	0.56	6.08	3.40
5	CS05	13.5	19.8	0.52	4.71	2.45
6	CS06	13.2	20.7	0.55	6.36	3.50
7	CS07	13.3	17.8	0.62	4.00	2.48
8	CS08	13.1	18.7	0.6	5.31	3.18
				Mean:	5.39	3.04
				SD:	±1.09	±0.60

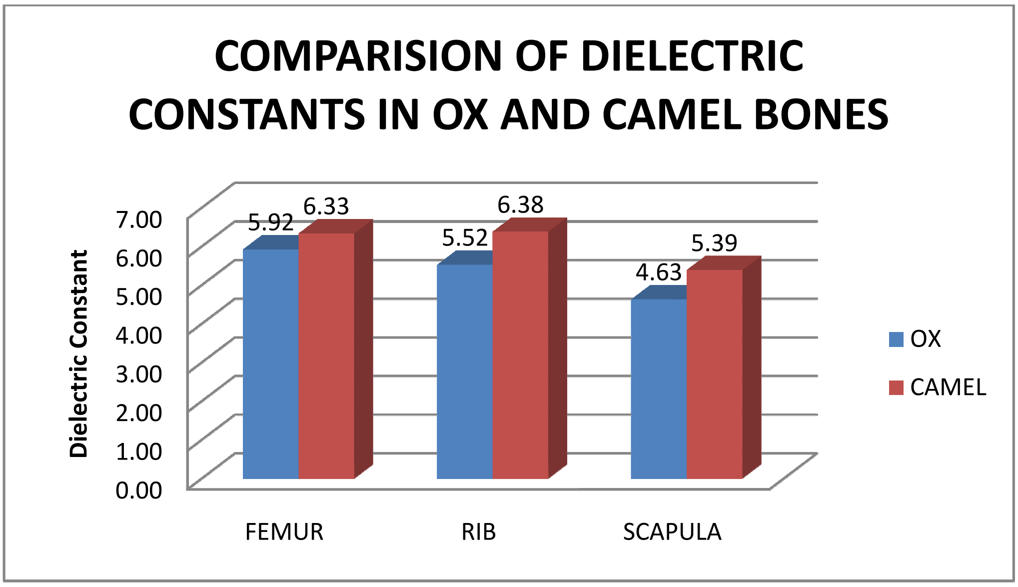
COMPARISION OF DIELECTRIC CONSTANTS IN OX AND CAMEL BONES
Dielectric Constant
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5.92
6.33
5.52
6.38
4.63
5.39
FEMUR
RIB
SCAPULA
OX
CAMEL

Fig. 1

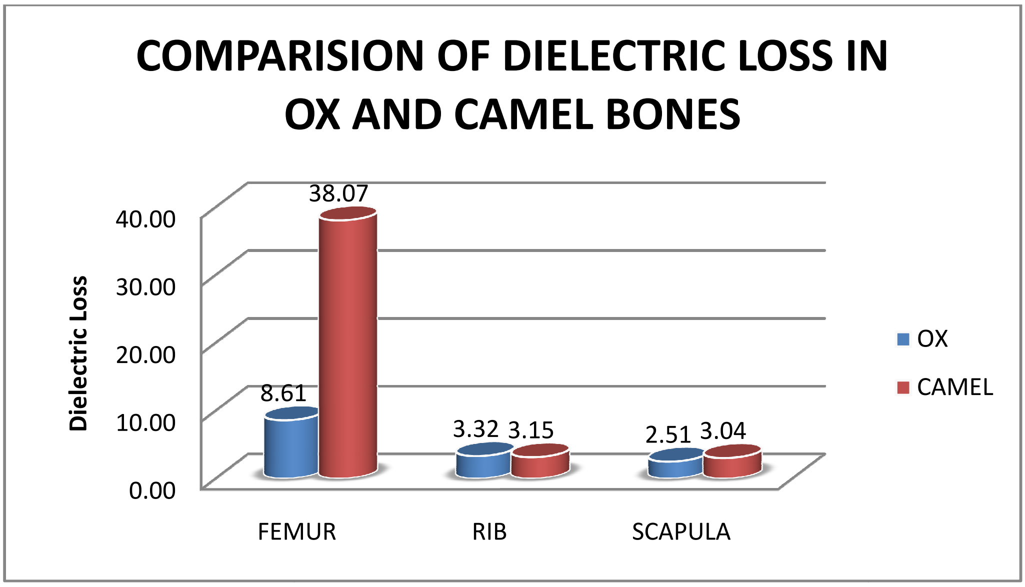
COMPARISION OF DIELECTRIC LOSS IN OX AND CAMEL BONES
Dielectric Loss
40.00
30.00
20.00
10.00
0.00
8.61
38.07
3.32
3.15
2.51
3.04
FEMUR
RIB
SCAPULA
OX
CAMEL

Fig. 2